Sneutrino Dark Matter in the $U(1)'$-extended MSSM

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based on the work with K. Matchev and S. Nasri [hep-ph/0702223]

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Why Supersymmetric DM?

2 major problems of the SM

1. gauge hierarchy problem (particle physics)
2. absence of good DM candidate (cosmology)

SUSY provides a common solution.

1. Superpartners cancel divergence in δM_h^2.
2. Lightest superpartner (LSP) is stable (with R-parity).

The neutral LSP is a well-motivated CDM candidate.

Identifying viable Supersymmetric DM candidates is important both in cosmology and particle physics.

Supersymmetric DM candidates in the MSSM

To be a viable CDM candidate (assuming sole DM)

1. right relic density ($\Omega_{\mathrm{DM}} h^2 = 0.111^{+0.011}_{-0.015}$ from 2σ WMAP+SDSS)

2. avoid direct detection ($\sigma_n^{\mathrm{SI}} \lesssim 10^{-7}\mathrm{pb}$ from CDMS)

CDM candidates in the MSSM

- neutralino ($\widetilde{B}^0$, $\widetilde{W}_3^0$, $\widetilde{H}_1^0$, $\widetilde{H}_2^0$) [spin 1/2] $\rightarrow$ good candidate

- sneutrino ($\widetilde{\nu}_L$) [spin 0] $\rightarrow$ died out

Sneutrino CDM candidate died out in the MSSM.

Right relic density requires $M_{\tilde{\nu}_L} \gtrsim 550\,\mathrm{GeV}$. Otherwise, it annihilates too fast. Such a heavy $\tilde{\nu}_L$ should have been seen in direct detection already. [Falk, Olive, Srednicki (1994)]

$$\sigma_n^{\mathrm{SI}} \sim G_F^2 \mu_{n-\mathrm{DM}}^2 \sim 0.1\mathrm{pb} \gg 10^{-7}\mathrm{pb}\,(\mathrm{CDMS})$$

Few studies were done on this subject since then. The lightest neutralino ($\widetilde{\chi}_1^0$) is the only viable CDM candidate in the MSSM. ("SUSY DM" has been considered often as a synonym of the "neutralino DM".)

But, it is true only in the MSSM. The alternative Supersymmetric SM may have different Supersymmetric CDM candidates.

Right-handed sneutrino

Neutrino has mass. ν_R can explain neutrino mass.

What about the sneutrino DM candidate in the "MSSM+$(\nu_R, \widetilde{\nu}_R)$"?

People have considered a mixture of the LH and RH sneutrinos (with a fine-tuned mixing).

Also the non-thermal RH sneutrino DM (either by extremely small Yukawa coupling or low reheating temperature) were considered.

[Arkani-Hamed, Hall, Murayama, Smith, Weiner (2000)]

[Asaka, Ishiwata, Moroi (2006)]

[Gopalakrishna, de Gouvea, Porod (2006)]

Brief review of the $U(1)'$-extended MSSM

Fine-tuning problem in the MSSM

$$W_{\text{MSSM}} = \mu H_2 H_1 + y_E H_1 L E^c + y_D H_1 Q D^c + y_U H_2 Q U^c$$

$\mu \sim \mathcal{O}$(EW) to be free from fine-tuning in the EW symmetry breaking.

The MSSM does not provide the reason (μ-problem). [Kim, Nilles (1984)]

We may need to extend the MSSM with a new symmetry.

$U(1)'$-extended MSSM (UMSSM) as a cure

Extend the MSSM with a new symmetry, $U(1)'$, and a Higgs singlet, S.

$$W_{\mathrm{U(1)'-MSSM}} = hSH_2H_1 + y_E H_1 L E^c + y_D H_1 Q D^c + y_U H_2 Q U^c$$
$$+(\mathrm{exotics}) + (\mathrm{RH\ neutrinos})$$

- Forbid original μ-term ($\mu H_1 H_2$): $Q'_{H_1} + Q'_{H_2} \neq 0$.
- Allow effective μ-term (hSH_1H_2): $Q'_S + Q'_{H_1} + Q'_{H_2} = 0$.

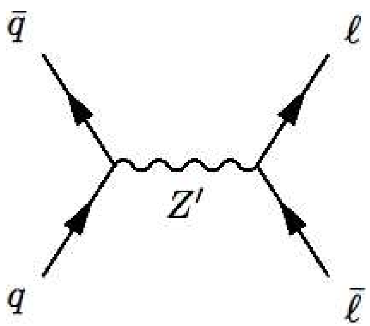
After S gets TeV scale VEV $\langle S \rangle$, $U(1)'$ symmetry is broken and

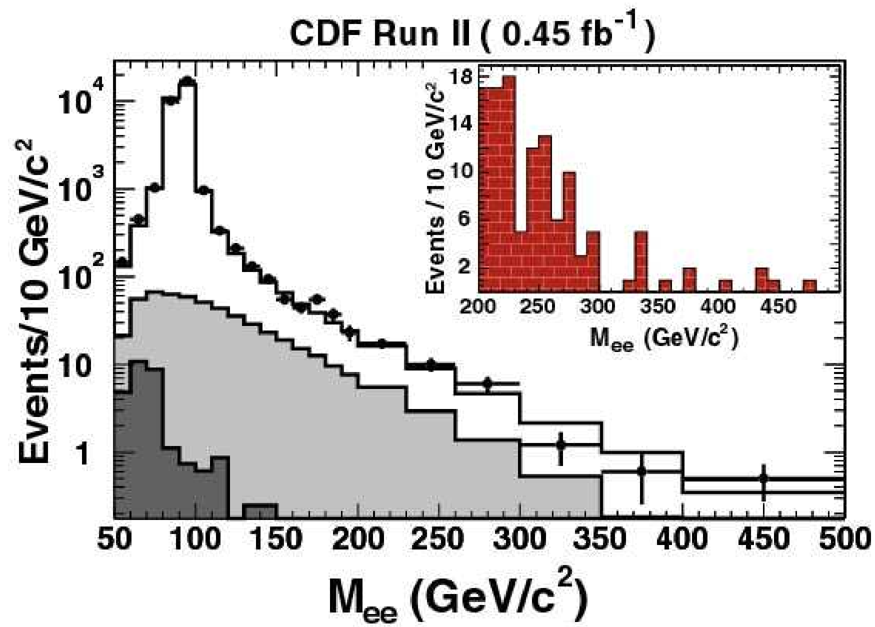
$$\begin{aligned} \mu_{\mathrm{eff}} &= h\langle S \rangle &&\sim \mathcal{O}(\text{EW}) \\ M_{Z'} &\sim g_{Z'} Q'_S \langle S \rangle &&\sim \mathcal{O}(\text{EW/TeV}) \end{aligned}$$

$\mu \sim \mathcal{O}$(EW) is naturally given by the $U(1)'$ scale (No μ-problem).

A new gauge boson (Z') of EW/TeV scale is also predicted.

Current collider bounds on $M_{Z'}$





Model	$Z'_{\rm SM}$	Z'_χ	Z'_ψ	Z'_η
Bound	860	735	725	745

[CDF collaboration (2006)]

References for the $U(1)'$-extended MSSM

Specific $U(1)'$ breaking scalar potential and exotic field contents are model-dependent. (We do not specify them here.)

Examples of specific Supersymmetric $U(1)'$ models :

- Superstring-motivated model [Cvetic, Demir, Espinosa, Everett, Langacker (1997)]
- E_6 GUT-motivated model [Langacker, Wang (1998)] [King, Moretti, Nevzorov (2005)]
- Chiral models [Cheng, Dobrescu, Matchev (1998)] [Erler (2000)]
- Multiple singlets model [Erler, Langacker, Li (2002)]
- Non-exotic, non-holomorphic model [Demir, Kane, Wang (2005)]

Supersymmetric DM candidates in the UMSSM

CDM candidates in the UMSSM

- neutralino ($\widetilde{B}^0$, $\widetilde{W}^0_3$, $\widetilde{H}^0_1$, $\widetilde{H}^0_2$, $\widetilde{Z}'$, $\widetilde{S}$) [spin 1/2] $\longrightarrow$ still good candidate
  [de Carlos, Espinosa (1997)] [Barger, Kao, Langacker, HL (2004)]
  [Barger, Langacker, Lewis, McCaskey, Shaughnessy, Yencho (2007)]

- sneutrino ($\widetilde{\nu}_L, \widetilde{\nu}_R$) [spin 0] $\longrightarrow$ not investigated

Possible RH neutrino terms in the superpotential

- mN^cN^c : not allowed (since we need $Q'_{\nu_R} \neq 0$)
- SN^cN^c : Majorana mass term ($\langle S \rangle \sim$ TeV)
- LH_2N^c : Dirac mass term

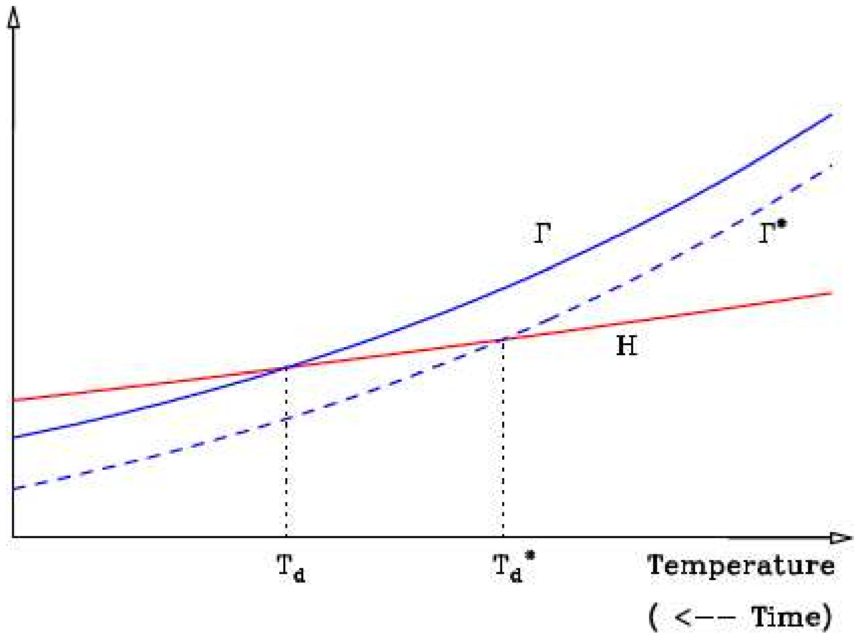
With a Dirac neutrino with non-renormalizable mass term such as

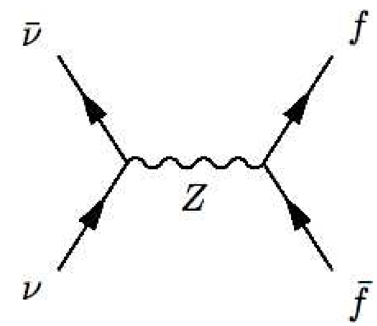
$$\left(\frac{S}{M}\right) LH_2N^c$$ [Langacker (1998)]

small neutrino mass $m_\nu \lesssim 0.1 \text{ eV}$ can be explained (with $M \sim 10^{14}$ GeV). A-term is also suppressed in the same way. The decoupling of the $\widetilde{\nu}_R$ from the $\widetilde{\nu}_L$ is naturally obtained.

We assume Dirac neutrinos for simplicity, and assume $\widetilde{\nu}_R$ is the LSP.

BBN constraint on $M_{Z'}$ with Dirac neutrinos (extra light d.o.f.)





$$\Gamma(T) \equiv n \langle \sigma v \rangle \approx G_W^2 T^5$$

SM neutrino : $G_W \propto \dfrac{g_Z^2}{M_Z^2}$: weak coupling constant

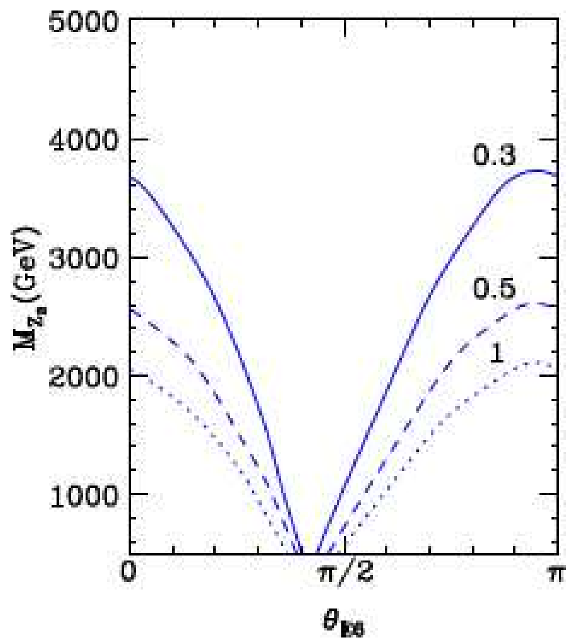
$\nu_R : G_{SW} \propto \dfrac{g_{Z'}^2}{M_{Z'}^2}$: super-weak coupling constant

$G_{SW} \ll G_W$ (because $M_{Z'} \gg M_Z$)

$\rightarrow$ earlier decoupling

$\rightarrow$ less contribution to ^{4}He abundance (ΔN)

[Steigman, Olive, Schramm (1979)]

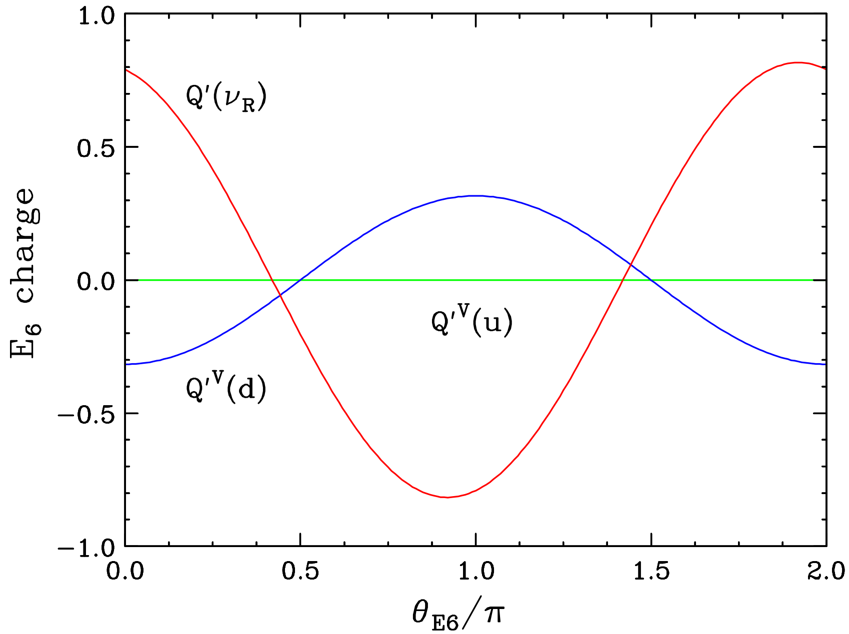


[Barger, Langacker, HL (2003)]

θ_{E6} is the parameter of the charge assignments in the E_6 charge assignments. ($\theta_{E6} \simeq 0.42\pi$ is where $Q'_{\nu_R} = 0$.)

E_6 charge assignments

$$Q'(\theta_{E6}) = Q'_\chi \sin\theta_{E6} + Q'_\psi \cos\theta_{E6}$$



Field	Q_χ	Q_ψ
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$-\frac{1}{2\sqrt{10}}$	$\frac{1}{2\sqrt{6}}$
u_R	$\frac{1}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
d_R	$-\frac{3}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\frac{3}{2\sqrt{10}}$	$\frac{1}{2\sqrt{6}}$
ν_R	$\frac{5}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
e_R	$\frac{1}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$

[for Q'^V_u, Q'^V_d, Q'_{ν_R}]

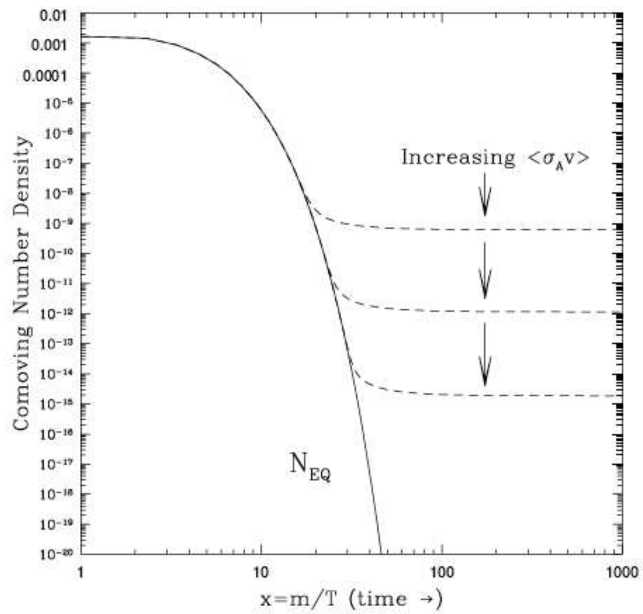
$$Q'^V_u = (Q'_{u_R} + Q'_{u_L})/2 = 0 \qquad Q'^V_d = (Q'_{d_R} + Q'_{d_L})/2 = -\frac{1}{10}\cos\theta_{E6}$$

For $\theta_{E6} \sim 0.5\pi$, $\sigma_n^{\rm SI} \sim 0$.

Relic density of the Sneutrino DM

Boltzmann equation and freeze-out of DM

$$\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left(n^2 - n_{\mathrm{eq}}^2 \right)$$



$$\Omega_{\mathrm{DM}} \equiv \frac{\rho_{\mathrm{DM}}}{\rho_c} = \frac{n_{\mathrm{DM}} M_{\mathrm{DM}}}{\rho_c}$$

Boltzmann equation for particle ($\widetilde{\nu}_R$) and anti-particle ($\widetilde{\nu}_R^*$)

$$\frac{dn_{\widetilde{\nu}_R}}{dt} = -3Hn_{\widetilde{\nu}_R} - \left\langle \sigma_{\widetilde{\nu}_R\widetilde{\nu}_R} v \right\rangle \left(n_{\widetilde{\nu}_R}^2 - n_{\widetilde{\nu}_R}^{\mathrm{eq}2}\right) - \left\langle \sigma_{\widetilde{\nu}_R\widetilde{\nu}_R^*} v \right\rangle \left(n_{\widetilde{\nu}_R} n_{\widetilde{\nu}_R^*} - n_{\widetilde{\nu}_R}^{\mathrm{eq}} n_{\widetilde{\nu}_R^*}^{\mathrm{eq}}\right)$$

$$\frac{dn_{\widetilde{\nu}_R^*}}{dt} = -3Hn_{\widetilde{\nu}_R^*} - \left\langle \sigma_{\widetilde{\nu}_R^*\widetilde{\nu}_R^*} v \right\rangle \left(n_{\widetilde{\nu}_R^*}^2 - n_{\widetilde{\nu}_R^*}^{\mathrm{eq}2}\right) - \left\langle \sigma_{\widetilde{\nu}_R\widetilde{\nu}_R^*} v \right\rangle \left(n_{\widetilde{\nu}_R} n_{\widetilde{\nu}_R^*} - n_{\widetilde{\nu}_R}^{\mathrm{eq}} n_{\widetilde{\nu}_R^*}^{\mathrm{eq}}\right)$$

The total is given by

$$\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left(n^2 - n_{\mathrm{eq}}^2\right) \text{ with } n = n_{\widetilde{\nu}_R} + n_{\widetilde{\nu}_R^*}$$

For assumed $n_{\widetilde{\nu}_R} = n_{\widetilde{\nu}_R^*}$ (ie, no asymmetry between $\widetilde{\nu}_R$ and $\widetilde{\nu}_R^*$),

$$\sigma = \frac{1}{4}\left(\sigma_{\widetilde{\nu}_R\widetilde{\nu}_R} + 2\sigma_{\widetilde{\nu}_R\widetilde{\nu}_R^*} + \sigma_{\widetilde{\nu}_R^*\widetilde{\nu}_R^*}\right)$$

Sneutrino annihilation channels

1. $\widetilde{\nu}_R\widetilde{\nu}_R \to \nu\nu$, $\widetilde{\nu}^*_R\widetilde{\nu}^*_R \to \bar{\nu}\bar{\nu}$ ($\widetilde{Z}'$ mediated t-channel)
2. $\widetilde{\nu}_R\widetilde{\nu}^*_R \to f\bar{f}$ (Z' mediated s-channel)
3. $\widetilde{\nu}_R\widetilde{\nu}^*_R \to \nu\bar{\nu}$ ($\widetilde{Z}'$ mediated t-channel)
4. $\widetilde{\nu}_R\widetilde{\nu}^*_R \to Z'Z'$ ($\widetilde{\nu}_R$ mediated t-channel and 4-point vertex)

We assume the other 2 families of the sneutrinos and/or NLSP are heavy enough to neglect coannihilations.

(A Majorana mass term SN^cN^c would have provided more channels.)

For a non-relativistic (cold) dark matter, we can use the Taylor expansion.

$$\langle \sigma v \rangle \approx a + b v^2$$

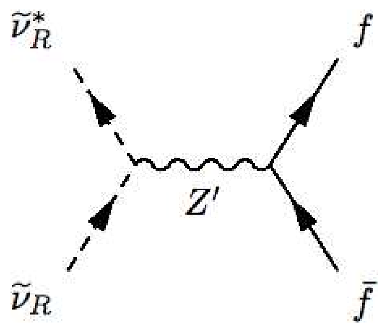
a (s-wave) and b (p-wave) term for each channel:

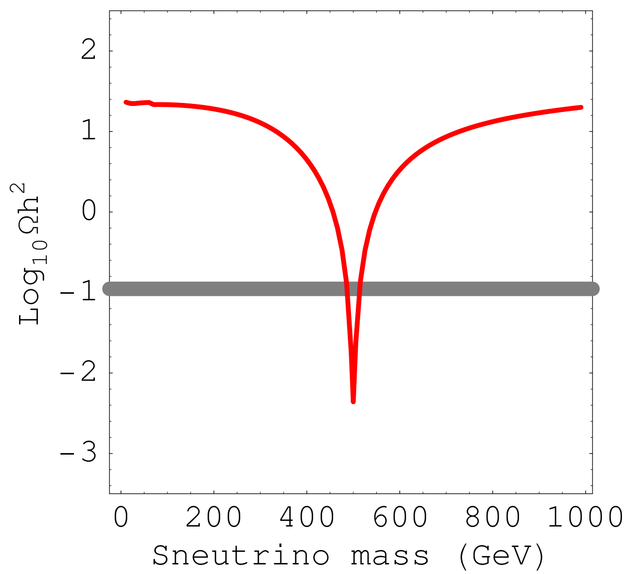
$$
\begin{aligned}
a_{\nu\nu} &= a_{\bar{\nu}\bar{\nu}} = g_{Z'}^4 Q'^4_{\nu_R} M^2_{\tilde{Z}'} / \left(\pi (M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R})^2\right) \\
b_{\nu\nu} &= b_{\bar{\nu}\bar{\nu}} = -\, g_{Z'}^4 Q'^4_{\nu_R} M^2_{\tilde{Z}'} M^2_{\tilde{\nu}_R} (3M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R}) / \left(3\pi (M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R})^4\right) \\
a_{\nu\bar{\nu}} &= 0 \\
b_{\nu\bar{\nu}} &= g_{Z'}^4 M^2_{\tilde{\nu}_R} Q'^2_{\nu_R} \left((M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R})^2 (Q'^2_{\nu_L} + Q'^2_{\nu_R}) + 2(M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R})(4M^2_{\tilde{\nu}_R} - M^2_{\tilde{Z}'}) Q'_{\nu_L} Q'_{\nu_R}\right. \\
&\quad \left. + (-4M^2_{\tilde{\nu}_R} + M^2_{Z'})^2 Q'^2_{\nu_R}\right) / \left(12\pi (M^2_{\tilde{Z}'} + M^2_{\tilde{\nu}_R})^2 \left|-4M^2_{\tilde{\nu}_R} + M^2_{Z'} - i M_{Z'} \Gamma_{Z'}\right|^2\right) \\
a_{f\bar{f}} &= 0 \\
b_{f\bar{f}} &= g_{Z'}^4 Q'^2_{\nu_R} (M^2_{\tilde{\nu}_R} - M^2_f)^{1/2} \left(4M^2_{\tilde{\nu}_R} (Q'^2_{f_L} + Q'^2_{f_R} - M^2_f (Q'^2_{f_L} - 6Q'_{f_L} Q'_{f_R} + Q'^2_{f_R})\right) \\
&\quad / \left(48\pi M_{\tilde{\nu}_R} \left|-4M^2_{\tilde{\nu}_R} + M^2_{Z'} - i M_{Z'} \Gamma_{Z'}\right|^2\right) \\
a_{Z'Z'} &= g_{Z'}^4 Q'^4_{\nu_R} (M^2_{\tilde{\nu}_R} - M^2_{Z'})^{1/2} \left(8M^4_{\tilde{\nu}_R} - 8M^2_{\tilde{\nu}_R} M^2_{Z'} + 3M^4_{Z'}\right) / \left(16\pi M^3_{\tilde{\nu}_R} (-2M^2_{\tilde{\nu}_R} + M^2_{Z'})^2\right) \\
b_{Z'Z'} &= g_{Z'}^4 Q'^4_{\nu_R} \left(-448 M^{10}_{\tilde{\nu}_R} + 1312 M^8_{\tilde{\nu}_R} M^2_{Z'} - 1528 M^6_{\tilde{\nu}_R} M^4_{Z'} + 900 M^4_{\tilde{\nu}_R} M^6_{Z'} - 254 M^2_{\tilde{\nu}_R} M^8_{Z'}\right. \\
&\quad \left. + 27 M^{10}_{Z'}\right) / \left(384\pi M^3_{\tilde{\nu}_R} (M^2_{\tilde{\nu}_R} - M^2_{Z'})^{1/2} (-2M^2_{\tilde{\nu}_R} + M^2_{Z'})^4\right)
\end{aligned}
$$

Assumptions on numerical analysis

1. GUT-motivated coupling constant $g_{Z'} = \sqrt{\frac{5}{3}} g_Y \equiv g_1$
2. Exotic chiral fields, if any, are heavy enough to be neglected.
3. $\widetilde{Z}'$ (Z'-ino) is decoupled from the rest of the neutralinos.
4. For $\Gamma_{Z'}$, consider only SM fermions and $\widetilde{\nu}_R$ only.
5. Adopt E_6 charge assignment.

Z'-resonance region ($M_{\tilde{\nu}_R} \sim M_{Z'}/2$)



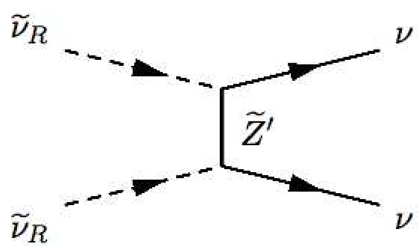


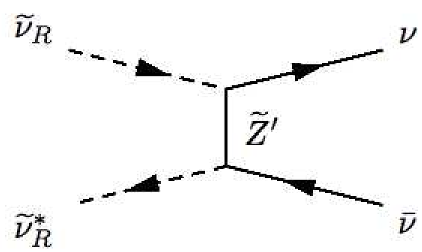
$$a = 0,\ b \propto \frac{1}{\Gamma_{Z'}^2}$$

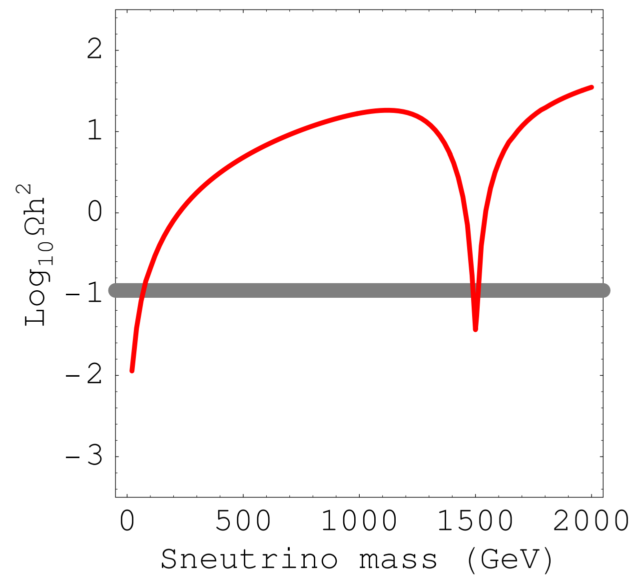
$$\left(\mathrm{ex: for}\ M_{Z'} = 1\ \mathrm{TeV},\ M_{\tilde{Z}'} = 3\ \mathrm{TeV},\ \theta_{E6} = 0.3\pi\right)$$

Right relic density can be obtained with $M_{\tilde{\nu}_R} \sim M_{Z'}/2$.

$\widetilde{Z}'$-mediation region ($M_{\widetilde{\nu}_R} < M_{\widetilde{Z}'} \sim$ sufficiently small)





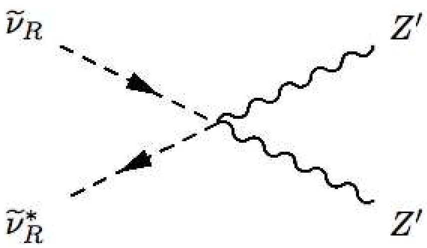


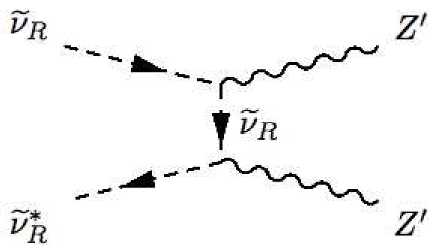
$$a_{\nu\nu} \propto \frac{1}{M^2_{\widetilde{Z}'}} \qquad b_{\nu\bar{\nu}} \propto \frac{1}{M^2_{\widetilde{Z}'}}$$

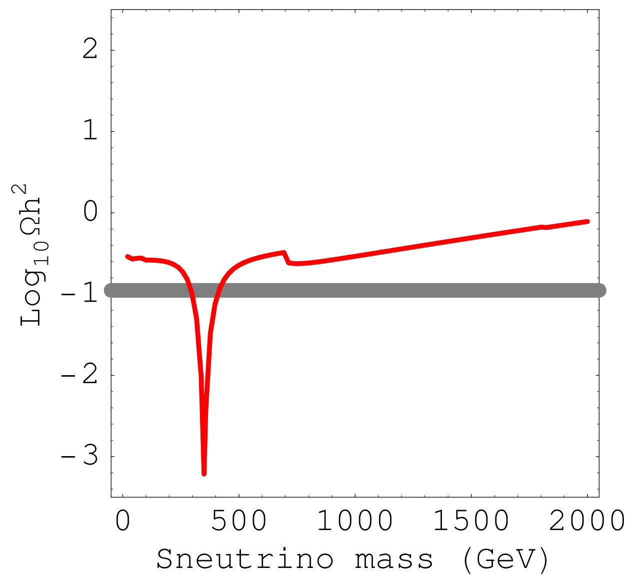
$$\left(\mathrm{ex: for}\ M_{Z'} = 3\ \mathrm{TeV},\ M_{\widetilde{Z}'} = 1.5 \times M_{\widetilde{\nu}_R},\ \theta_{E6} = 0.3\pi\right)$$

Right relic density can be obtained with $M_{\widetilde{\nu}_R} < M_{Z'}/2$.

$Z'Z'$ region ($M_{\tilde{\nu}_R} > M_{Z'}$)





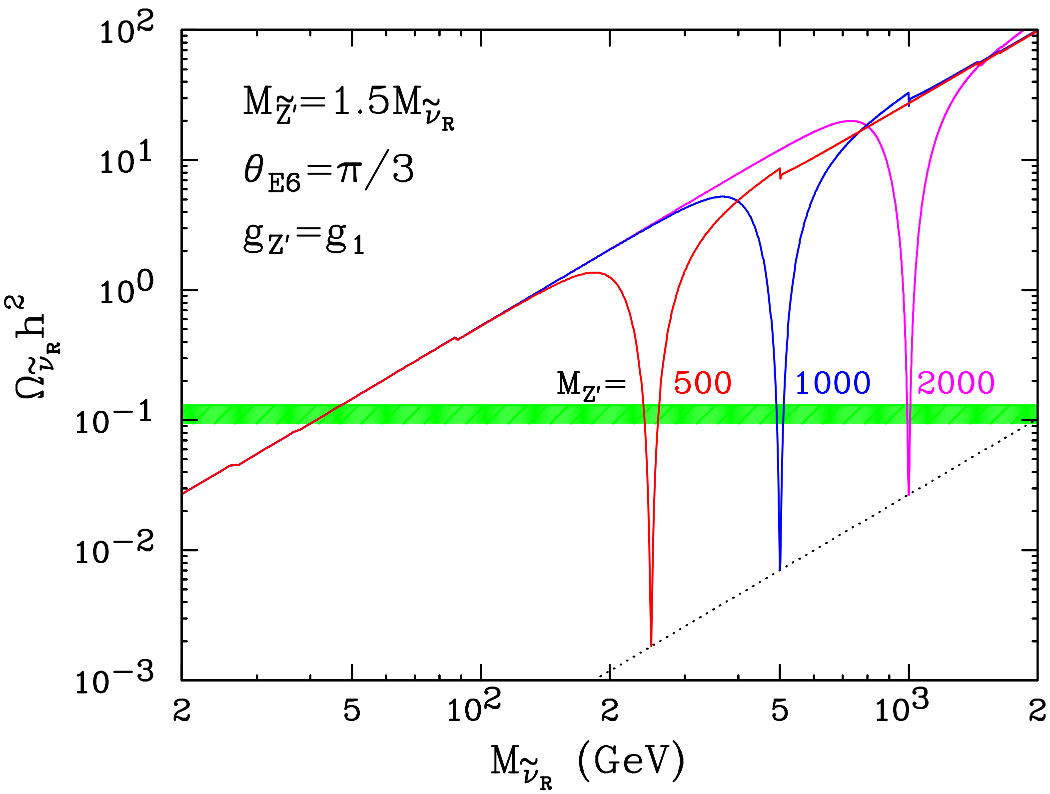


$$a \propto \frac{1}{M^2_{\tilde{\nu}_R}}$$

$$\left(\mathrm{ex: for}\ M_{Z'} = 0.7\ \mathrm{TeV},\ M_{\tilde{Z}'} = 2\ \mathrm{TeV},\ \theta_{E6} = \pi\right)$$

Not likely right relic density for $M_{\tilde{\nu}_R} > M_{Z'}$ (by itself) with E_6 charge assignments.

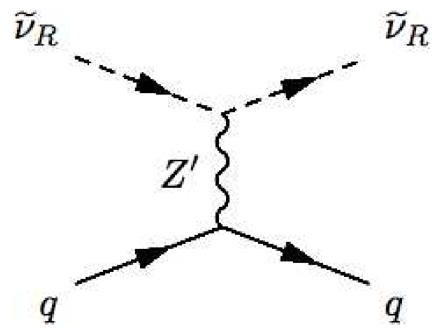
Relic densities for various $M_{Z'}$ values (with other values fixed)



For a wide range of the $M_{\tilde{\nu}_R}$, it is possible to have the right relic density with suitable choices of $M_{Z'}$, $M_{\tilde{Z}'}$, θ_{E6}.

Direct detection of the Sneutrino DM

Effective lagrangian at quark level



$$\mathcal{L}_{\rm eff} = i\frac{g_{Z'}^2}{M_{Z'}^2} Q'_{\nu_R} (\widetilde{\nu}_R^* \partial_\mu \widetilde{\nu}_R - \partial_\mu \widetilde{\nu}_R^* \widetilde{\nu}_R) \sum_{q_i = u,d} [Q'^V_{q_i} \bar{q}_i \gamma^\mu q_i + Q'^A_{q_i} \bar{q}_i \gamma^\mu \gamma^5 q_i]$$

with

$$Q'^V_q \equiv (Q'_{q_R} + Q'_{q_L})/2 \qquad Q'^A_q \equiv (Q'_{q_R} - Q'_{q_L})/2$$

In the non-relativistic limit, the time component ($\mu = 0$) of the vector current (scalar interaction) dominates.

Effective lagrangian at nucleus level

$$\mathcal{L}_{\rm eff}^{N} = \lambda_N \widetilde{\nu}_R^* \partial_0 \widetilde{\nu}_R \bar{N} \gamma^0 N$$

with

$$\lambda_N \equiv \left(\frac{g_{Z'}^2}{M_{Z'}^2} Q'_{\nu_R} \right) \left(Z[2Q_u'^V + Q_d'^V] + (A-Z)[Q_u'^V + 2Q_d'^V] \right)$$

The cross-section (averaged per nucleon) is

$$\sigma_n^{\rm SI} = \frac{\lambda_N^2}{\pi A^2} \left(\frac{M_n M_{\widetilde{\nu}_R}}{M_n + M_{\widetilde{\nu}_R}} \right)^2$$

$$\sigma_n^{\rm SI} \sim \left(\frac{g_{Z'}^2}{M_{Z'}^2}\right)^2 \left(Q'_{\nu_R} Q'^V_{u,d}\right)^2 \mu_n^2$$

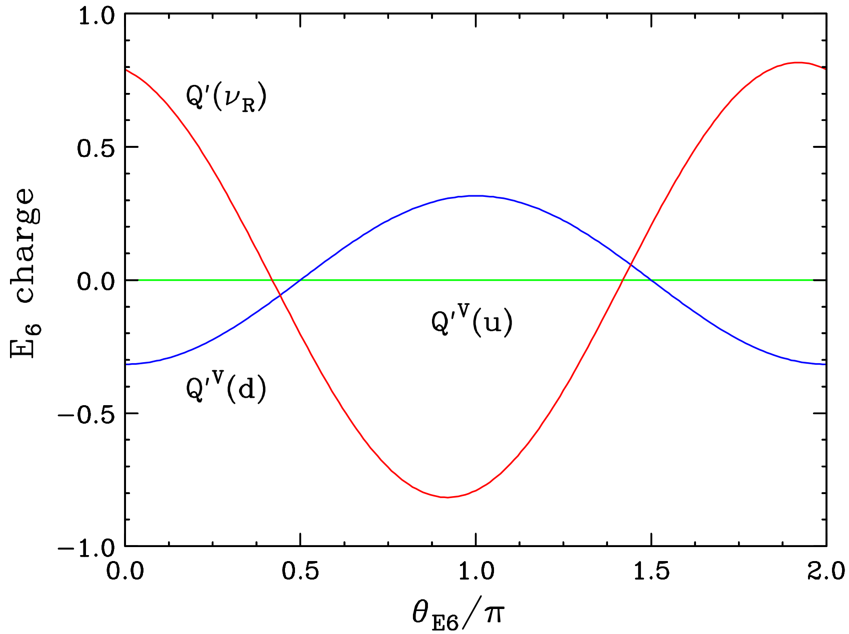
(Cf. In the MSSM, the $\widetilde{\nu}_L$ has $\sigma_n^{\rm SI} \sim G_F^2 \mu_{n-{\rm DM}}^2 \sim 0.1{\rm pb}$.)

To escape the direct detection constraint,

- $M_{Z'}$ should be large OR
- Q'^V_u, Q'^V_d (quark vector couplings) should be small. (Q'_{ν_R} should be sizable for the right relic density.)

E_6 charge assignments

$$Q'(\theta_{E6}) = Q'_\chi \sin\theta_{E6} + Q'_\psi \cos\theta_{E6}$$



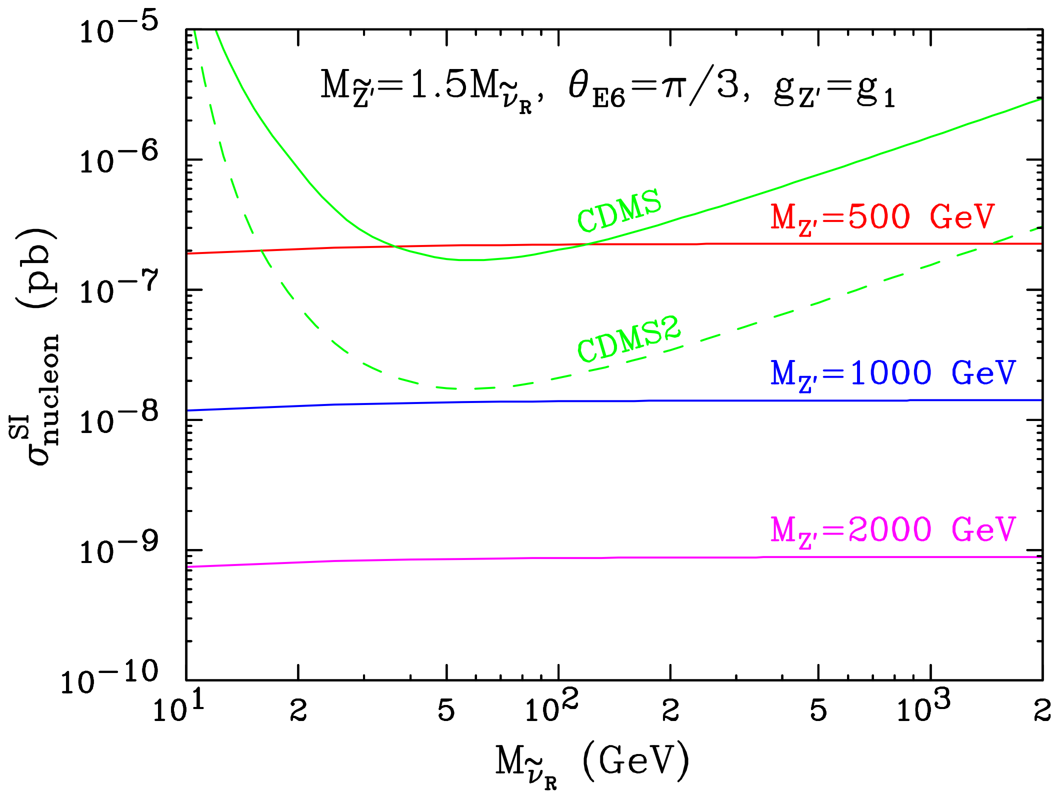
Field	Q_χ	Q_ψ
$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$-\frac{1}{2\sqrt{10}}$	$\frac{1}{2\sqrt{6}}$
u_R	$\frac{1}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
d_R	$-\frac{3}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\frac{3}{2\sqrt{10}}$	$\frac{1}{2\sqrt{6}}$
ν_R	$\frac{5}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$
e_R	$\frac{1}{2\sqrt{10}}$	$-\frac{1}{2\sqrt{6}}$

[for Q'^V_u, Q'^V_d, Q'_{ν_R}]

$$Q'^V_u = (Q'_{u_R} + Q'_{u_L})/2 = 0 \qquad Q'^V_d = (Q'_{d_R} + Q'_{d_L})/2 = -\frac{1}{10}\cos\theta_{E6}$$

For $\theta_{E6} \sim 0.5\pi$, $\sigma_n^{\rm SI} \sim 0$.

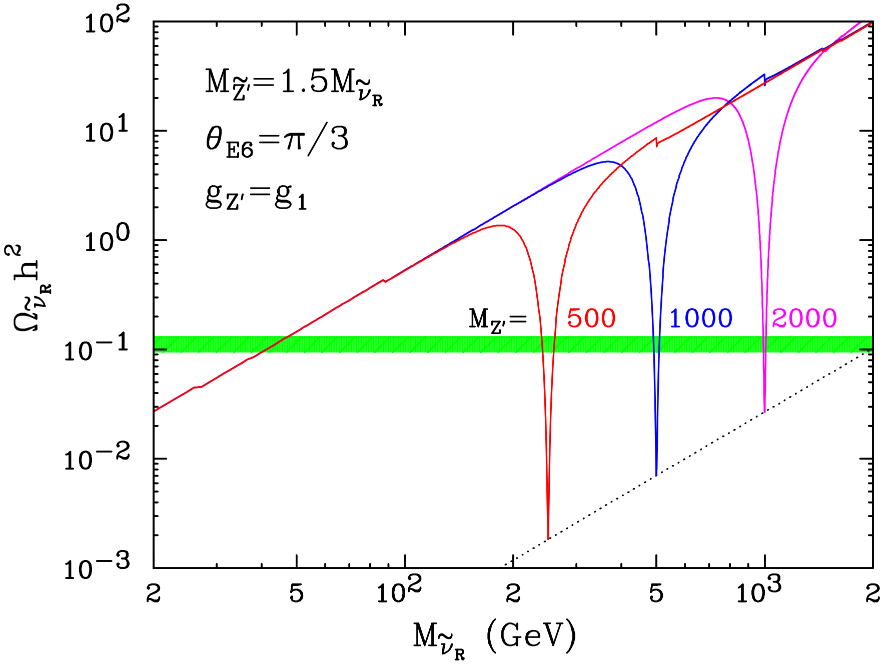
Predictions of $\sigma_n^{\rm SI}$ with the current (solid) and future (dash) CDMS

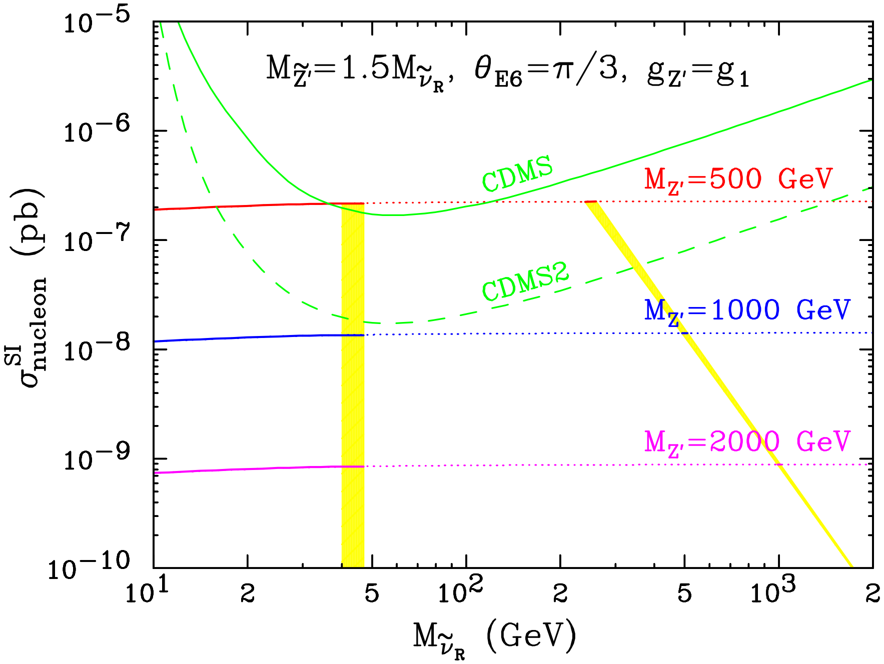


For fixed $\theta_{E6} = \pi/3 \rightarrow M_{Z'} = 0.5\ \mathrm{TeV}, 1\ \mathrm{TeV}, 2\ \mathrm{TeV}$.

For fixed $M_{Z'} = 1\ \mathrm{TeV} \rightarrow \theta_{E6} = 0.19\pi, \pi/3, 0.39\pi$. ($|Q'^V|$ drops.)

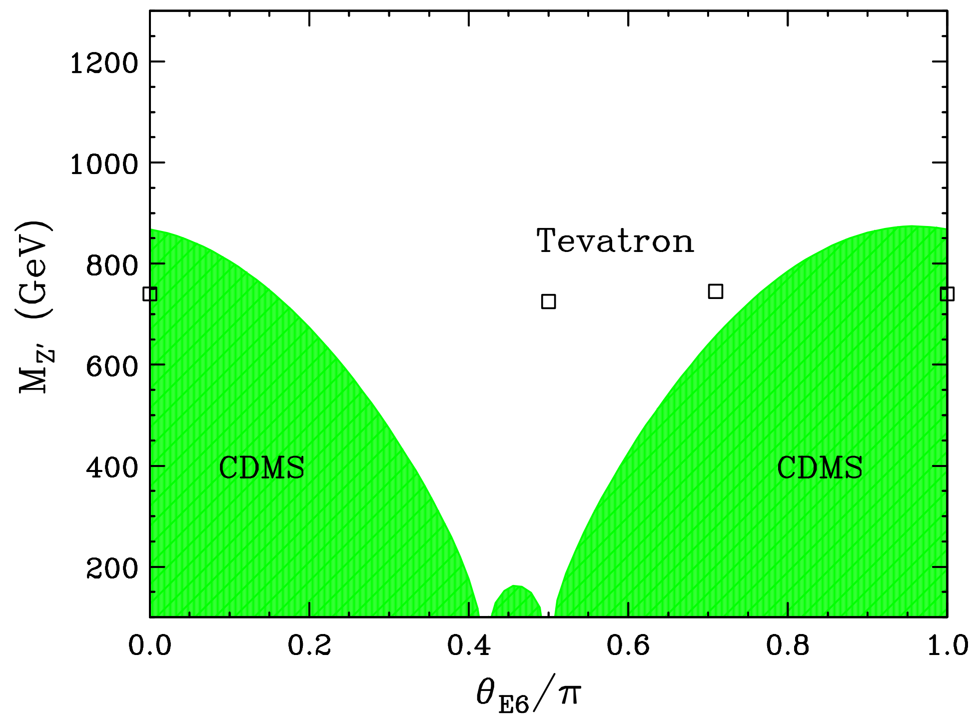
Predictions of $\sigma_n^{\rm SI}$ with the current (solid) and future (dash) CDMS





Yellow bands: right relic density ($\Omega_{\tilde{\nu}_R}h^2 \sim 0.1$) in the $\widetilde{Z}'$ mediation region ($M_{\tilde{\nu}_R} \sim 45$ GeV) and Z' mediation region ($M_{\tilde{\nu}_R} \sim M_{Z'}/2$).

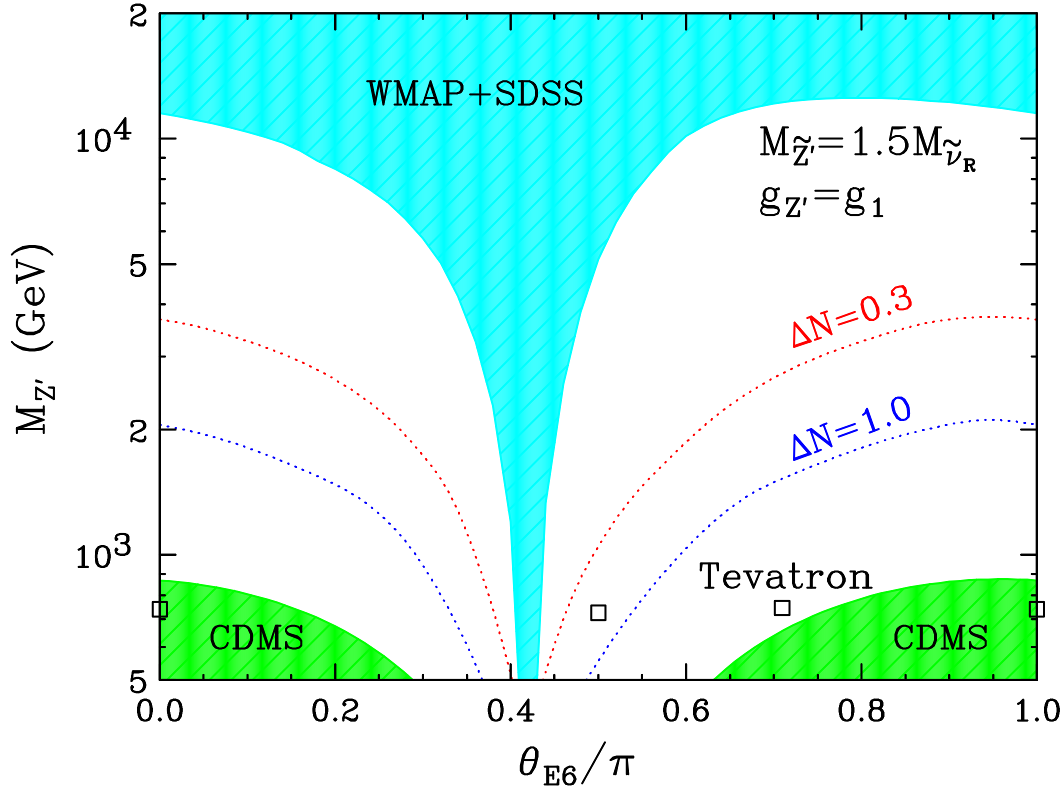
Constraints on ($M_{Z'}, \theta_{E6}$) from direct detection (for $M_{\widetilde{\nu}_R} \sim M_{Z'}/2$)



In the $\widetilde{\nu}_R$ CDM scenario, direct detection experiment outperforms the collider experiment in constraining Z' mass in some charge assignments. To avoid the current CDMS constraint, $M_{Z'} \gtrsim 1\ \mathrm{TeV}$ or $\theta_{E6} \sim 0.5\pi$ (where $Q'^{V}_{u,d} = 0$). Another singularity ($\theta_{E6} \simeq 0.42\pi$) is where $Q'_{\nu_R} = 0$.

Collection of constraints from collider, BBN, direct detection, relic density for the models with E_6 charge assignments

(for $M_{\tilde{\nu}_R} \sim M_{Z'}/2$)



Wide region of parameters survives after all experimental constraints.

Sneutrino is a viable thermal CDM candidate in the $U(1)'$-extended MSSM.

Summary and Outlook

- Although TeV scale SUSY is well-motivated, the MSSM is just one possibility (and has its own fine-tuning problem). The $U(1)'$-extended MSSM is conceivable as an alternative TeV scale SUSY SM.

- The sneutrino is revived as a viable CDM candidate in this naturally extended-MSSM (potentially a big success of the $U(1)'$ model).

- The sneutrino CDM scenario deserves more attention. It is a good Supersymmetric CDM candidate with spin 0, which has interesting implications on particle physics and cosmology. (`SPIRES` search : ”dark matter” hits ~ 5000, ”sneutrino dark matter” hits ~ 10.)